BE IT KNOWN that I, ***A. NIKITIN, A. SICIGNANO, D. YEREMIN, and T. GOLDBURT***, have invented certain new and useful improvements in

A METHOD OF CALIBRATION OF MAGNIFICATION OF MICROSCOPES HAVING DIFFERENT OPERATIONAL PRINCIPLES FOR BRINGING THEM TO A SINGLE, ABSOLUTE SCALE

of which the following is a complete specification:

This application is qualified as Small Entity
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BACKGROUND OF THE INVENTION

The present invention relates to methods of calibration of magnification of measuring microscopes.

Measuring microscopes are used in different areas of science and industry for measurements of sizes of various objects which have sizes from inches to angstroms. There is no microscope which is capable to measure objects in such a broad range of sizes. For measurements in centimeter, millimeter and micrometer subranges, optical measuring microscopes are the most convenient microscopes. The subrange of micrometer and nanometer sizes is covered by scanning electron measuring microscopes. In the area of nanometer, sub-nanometer and atom (angstrom) sizes, probe microscopes are utilized, such as scanning tunnel microscopes and atomic force microscopes. There are objects with intermediate sizes, which can be measured by microscopes of one type or another type. Typical examples are the features of modern integrating circuits which have submicron and nanometer sizes. These objects can be also measured with scanning electron microscopes or probe microscopes, depending on the nature and properties of the features to be measured. In these cases it is in principl

important that the results of measurement of the same object be identical, regardless of the type of microscope which is used for the measurements. The required coincidence of the results of measurements can be provided only when scales of magnification of all used microscopes are coordinated with one another, and ratios of such scales are established with a high accuracy.

This problem is very difficult to solve since there is no universal calibrating standard which would be suitable for calibration of optical measuring microscopes, scanning electron measuring microscopes and probe microscopes. For example the probe microscopes, due to their exceptionally high resolution, are calibrated with the use of a reference sample which is created by nature, in particular a pattern of atoms on the surface of monocrystals. This reference sample is however completely unsuitable for calibration of optical measuring microscopes and scanning electron measuring microscopes, since the resolution of the microscopes of this types is lower than required for visualization of the atom pattern, so that this pattern is not shown on the images of the microscopes of these two types and can not serve as a common standard.

Known attempts to use as a universal reference sample so-called "hand-made" objects have not been successful. U.S. patent no. 5,825,670 formally declares a possibility of use of a conventional diffraction grating as a reference sample for the probe microscope. However, it is stated in the patent that the topography of the grating must be preliminarily (in other words before calibration of the microscopes) determined with high accuracy. The reference does not however mention any method of characterization (i.e. measurement) of the topography of the diffraction grating. For such measurements, in turn, it is necessary to have a microscope which is preliminarily precisely calibrated. Therefore the possibility of use of diffraction grating as a reference sample for the probe microscope which is mentioned in this reference is just a declaration without a specific support. The obstacle in this approach is that the diffraction grating to be used can never be completely uniform: the pitch of the diffraction grating does not remain constant and it somewhat changes from one point of observation to another. This causes non-reproducibility of the calibration and significantly reduces its accuracy.

Coordination of scales of magnification of microscopes of any type can be provided only if all of the microscopes are calibrated in a single, absolute scale of sizes.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a method of calibration of magnification of scanning measuring microscopes with digital scan system performed, in absolute units.

In keeping with these objects and with others which will become apparent herein after, one feature of the present invention resides, briefly stated, in a method of calibration of magnification of a microscope with the use of a diffraction grating, comprising the steps of determining a mean period of a diffraction grating by irradiating the diffraction grating with an electromagnetic radiation having a known wavelength and analyzing a resulting diffraction pattern; determining a scattering of individual values of a period (pitch) of the diffraction grating by multiple measurements of periods of the diffraction grating by a microscope in pixels in one area in a microscope field of view, and calculating a mean value of the period and the scatter based on the measurements; determining a sufficient number of measurements of the period for providing an accepted statistic error of a magnification of the microscope; performing measurements corresponding to the determined

acceptable number of measurements, of individual values of the period in pixels in a plurality of portions of the diffraction grating; calculating a general mean value of the period in pixels based on the immediately preceding step; and finally calculating a parameter corresponding to the magnification of the microscope based on the determined mean value of the period of the diffraction grating.

When the method is performed in accordance with the present invention, it eliminates the disadvantages of the prior art and provides for the highly advantageous results which will be explained in detail herein below.

The novel features which are considered as characteristic for the present invention are set forth in particular in the appended claims. The invention itself, however, both as to its construction and its method of operation, together with additional objects and advantages thereof, will be best understood from the following description of specific embodiments when read in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a view showing an image of a test diffraction grating in a scanning electron microscope with a magnification 65K, wherein local inhomogenuities of a period or "sample nonuniformity" are clearly shown;

Figure 2 is a view showing a sequence of operations of the calibration of magnification in accordance with the present invention, wherein first operation is performed on optical goniometer while the other operations are performed in a microscope to be calibrated;

Figure 3 is a view showing an experiment for determination of an average optical period of the diffraction grating with the use of the goniometer.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A method of calibration of magnification is illustrated for a measuring optical microscope or a scanning electron microscope or a probe microscope and is performed with the use of a diffraction grating (Figure 1). The method includes first of all a measurement of a mean "optical" period T_0 of the diffraction grating in a standard difractometric experiment, for example in accordance with the formula:

$$T_0 = \frac{m\lambda}{\sin\theta_m}$$

wherein m is an order of diffraction, λ is a wavelength of a used monochromatic radiation which is known with a high accuracy, and θ_m is an angle of diffraction measured in the experiment for the radiation which is diffracted in the m order.

Then scatter ω of individual values of periods of the test diffraction grating is determined. For this purpose multiple measurements of the period T_i with one of the known methods are performed. It is performed on images of different individual periods of the diffraction grating which are selected randomly, with their positioning in the same

selected field of view of the microscopes, for example in its center. Then a preliminary mean value of the period T_{AVE} and a scatter ω are determined in accordance with the formulas:

$$T_{AVE} = \frac{\sum_{i=1}^{N} T_i}{N}$$

$$\omega = \sqrt{\frac{\sum_{i=1}^{N} \left(T_i - T_{AVE}\right)}{N}},$$

wherein i is a number of the measurement, T_i is an individual period value, N is a number of performed preliminarily measurements (usually 10-20). The values T_{AVE} and ω are measured in pixels.

The next step is determination of a sufficient number K of independent measurements of the period for providing the required statistic error σ of magnification of the microscope in accordance with the following formula

$$K \geq \left(\frac{\omega}{\sigma T_{AVE}}\right)^2$$

Based on the images obtained in the microscope to be calibrated, K of independent measurements of individual values of the period T_i in

pixels are performed. If the preliminary multiple measurements of the period were performed on the microscope to be attested, then the K measurements can include the results of the measurements performed during the preliminary step.

Thereafter a general mean value of the period in pixels is determined in accordance with the formula:

$$T_{GEN} = \frac{\sum_{i=1}^{K} T_i}{K}$$

The scale of magnification MAG of the microscope to be attested in the selected zone of its field of view is calculated:

$$MAG = \frac{L * T_{GEN}}{Q * T_0}$$

wherein L is a width of the screen (picture) on which a magnified image is observed, and Q is a number of pixels in a line.

In the practice of measurements with the use of a digital measuring microscope, instead of the magnification MAG often a

different parameter is utilized, namely a distance between "elements of breaking" of the image, or in other words pixels. Pixel length is PL. This characteristic is calculated from the results of the measurements performed in the previous steps in accordance with the following formula:

$$PL = \frac{T_0}{T_{GEN}}$$

All actions which are performed for the calibration of magnification in accordance with the present invention can be subdivided into three independent blocks.

The determination of the average "optical" period of the diffraction grating in absolute units. This operation which is identified as 1 in Figure 2 is performed with the use of an optical goniometer and not related in time and place to other operations. Modern optical goniometers allow to determine an angle of diffraction with an error of several angular seconds: (2 ÷5)". With the measurements of the angle of diffraction in the range of 40-60º, a relative error of measurement of the angle θ_m corresponds to approximately $1 \cdot 10^{-6}$. The wavelengths of some spectral lines which are suitable for performing a diffractometric experiment is known with the error of approximately $2 \cdot 10^{-7}$. This allows

to calculate a mean (optical) value of the period of diffraction grating T_0 in absolute units with error of a few thousands of a percent. Figure 2 shows a source of a monochromatic radiation 1, a stage of the goniometer with the diffraction grating 2 attached to it, and a counting device for measurement of an angle of diffraction θ_m which is not shown in the drawings since it is not important for the present invention.

The next group of operations is performed in a microscope to be calibrated. For achieving the final objective which is a precision calibration of magnification of the microscope, it is necessary to compare T_0 with the general mean value of the period measured on the microscope in pixels T_{GEN}. This mean value is calculated by standard method with the use of statistical rules. The number of the independent results of the individual measurements K which is involved in calculation of the general mean value depends on the quality of the diffraction grating, in particular on scatter ω of the results of individual measurements around the mean value T_{AVE} and also on the required accuracy of the calibration σ. The connection of this variables with the number of measurements K is shown in the formula presented herein above. For calculation of the scatter ω and the required number of measurements K operations 3, 4, and 6 are identified in Figure 2.

The last group of the operations is also performed in the microscope to be calibrated and includes performance of a series of K independent measurements of the period which is operation 7, a calculation of the general mean value T_{GEN} which is operation 8, and a calculation of scale of magnification MAG and a length of pixel PL which is operation 9.

In accordance with the theory of probability, an average square probable error of calibration includes probable errors of all operations performed during the process of calibration. An evaluation of possible errors of the procedures shown in Figure 2 can be performed in the following manner.

A. Relative error of the wavelength of the use of monochromatic radiation usually does not exceed $2 \cdot 10^{-7}$.

B. Error of detection of the angle of diffraction θ_m is taken here to be equal to 2 angular seconds, which corresponds to a relative error of determination of T_0 about $1 \cdot 10^{-5}$.

C. If it is established that the scatter of the individual values of the period of diffraction grating ω is 1.5% and the calculated value K is equal to 5000, then the probable error of calculation of the general mean period T_{GEN} is:

$$\varepsilon = \frac{0.015}{\sqrt{5000}} \cong 2 \cdot 10^{-4}$$

Full probable error of calibration of magnification can now be presented as follows:

$$\sigma = \sqrt{\left(2 \cdot 10^{-7}\right)^2 + \left(1 \cdot 10^{-5}\right)^2 + \left(2 \cdot 10^{-4}\right)^2} \cong 0.02\%,$$

Thus it can be qualified as a precision calibration of magnification.

The connection to absolute units of lengths is performed due to the use of monochromatic radiation, with the wavelength λ as shown in the above presented formula, which is known with the high accuracy in absolute units.

It will be understood that each of the elements described above, or two or more together, may also find a useful application in other types of constructions differing from the types described above.

While the invention has been illustrated and described as embodied in a method of calibration of magnification of microscopes having different operational principles for bringing them to a single, absolute scale, it is not intended to be limited to the details shown, since various modifications and structural changes may be made without departing in any way from the spirit of the present invention.

Without further analysis, the foregoing will so fully reveal the gist of the present invention that others can, by applying current knowledge, readily adapt it for various applications without omitting features that, from the standpoint of prior art, fairly constitute essential characteristics of the generic or specific aspects of this invention.

What is claimed as new and desired to be protected by Letters Patent is set forth in the appended claims.